The origin and development of rims in lunar soil grains

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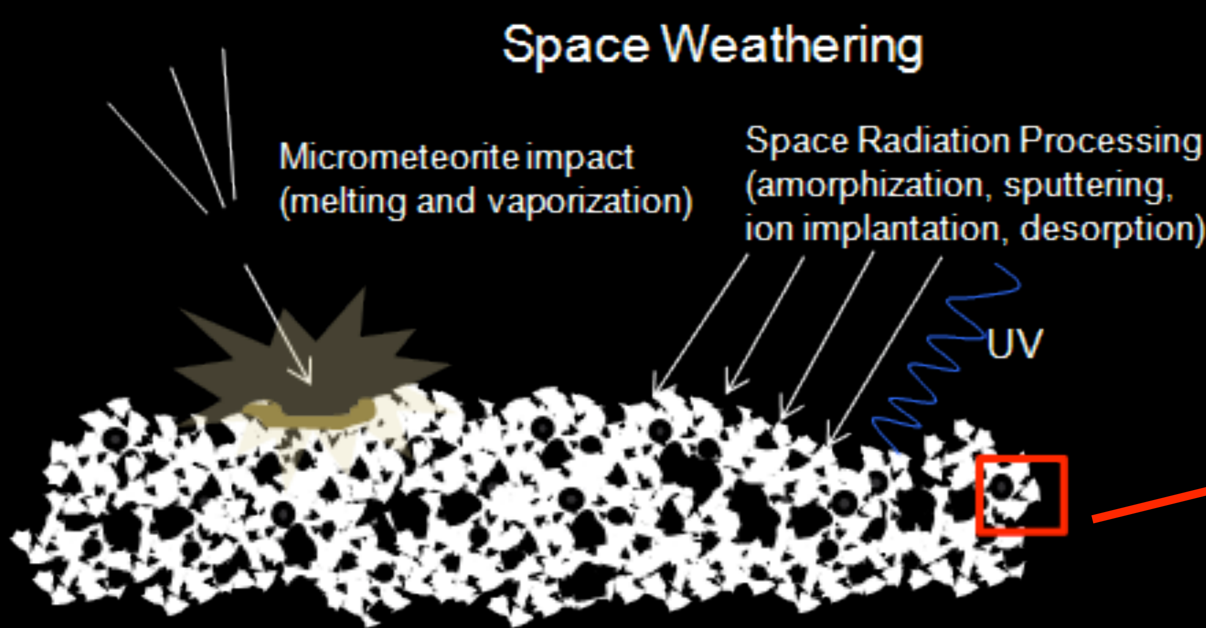
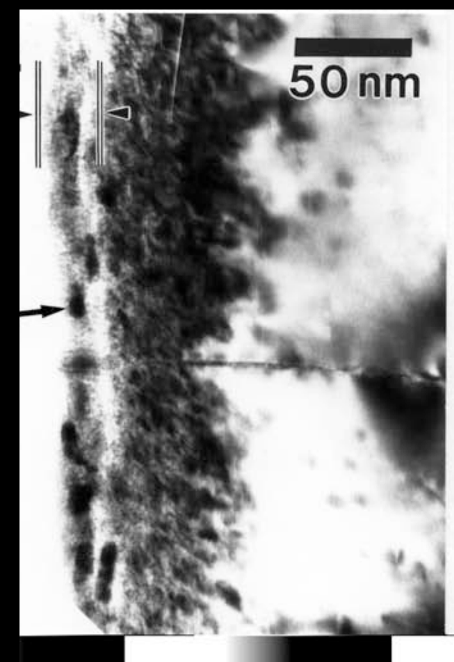
Space weathering effect



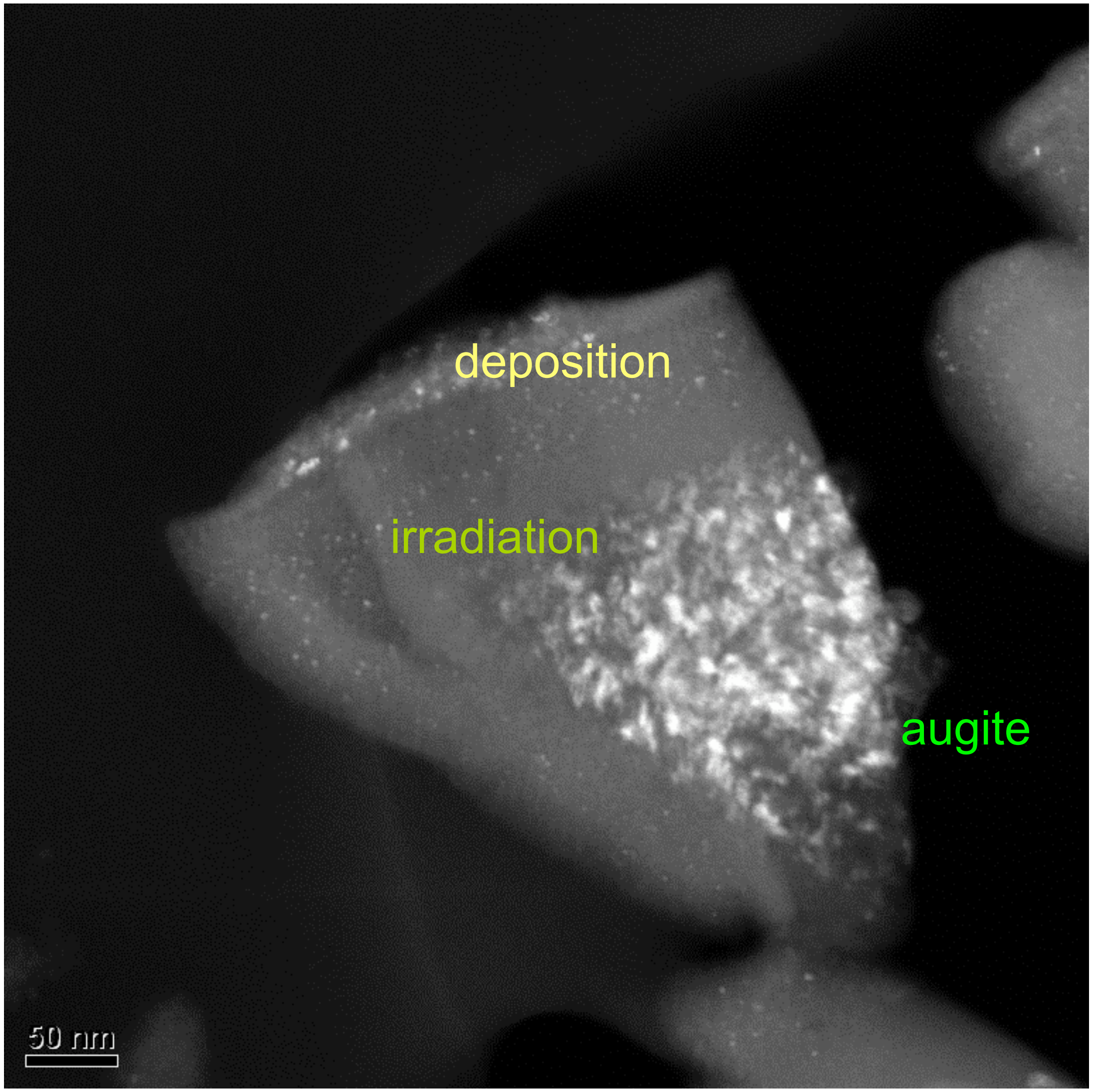


TEM grain outer margin or "rim"
(Christoffersen et al., 1996)

Dynamics of grain surfaces from lunar soil

- Evolution of the rims with exposure time, i.e. the length of time a grain resided within a few centimeters of lunar surface:

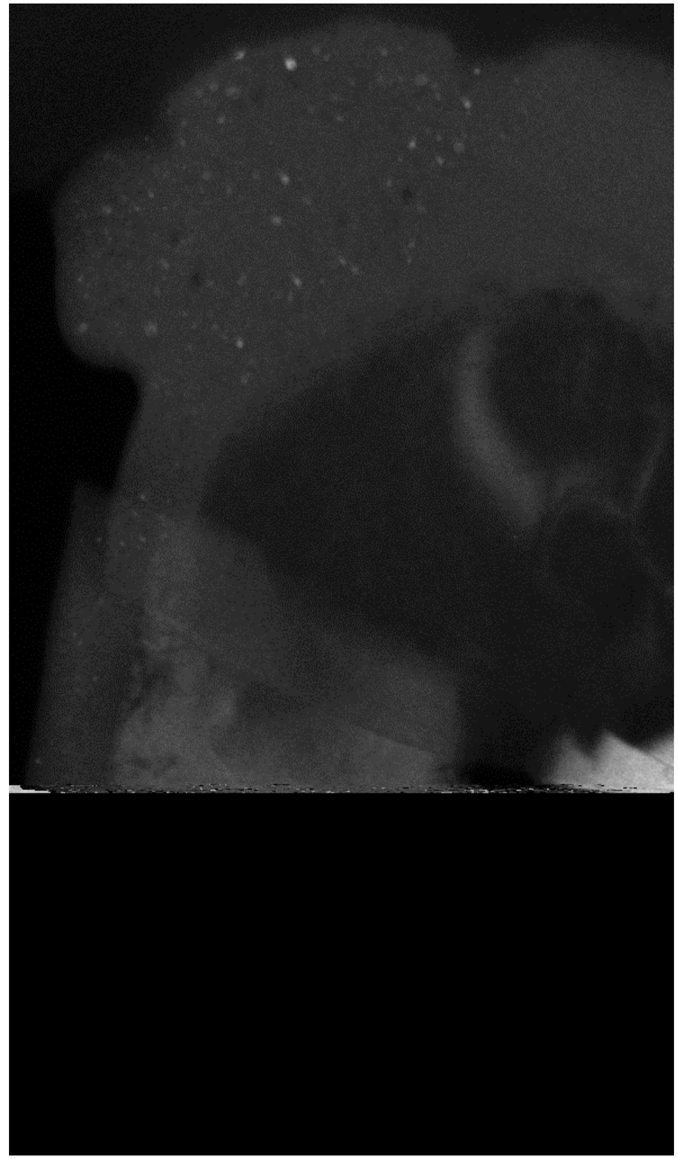
  - the thickness of the deposition/irradiation rims on grain surface
  - the deposition/irradiation rate
  - the formation of nanophase Fe metal.



Experimental methods

- TEM bright/dark field images: rim thickness *vs.* solar track density/exposure age
- STEM-EDS mapping: chemistry and stratigraphy of the rims
- EELS: Fe oxidation state to determine the origin of the rims
- Sample: 10084, <20 µm, high maturity (I_s/FeO=78), anorthite grains

Solar track density *vs.* deposition/irradiation

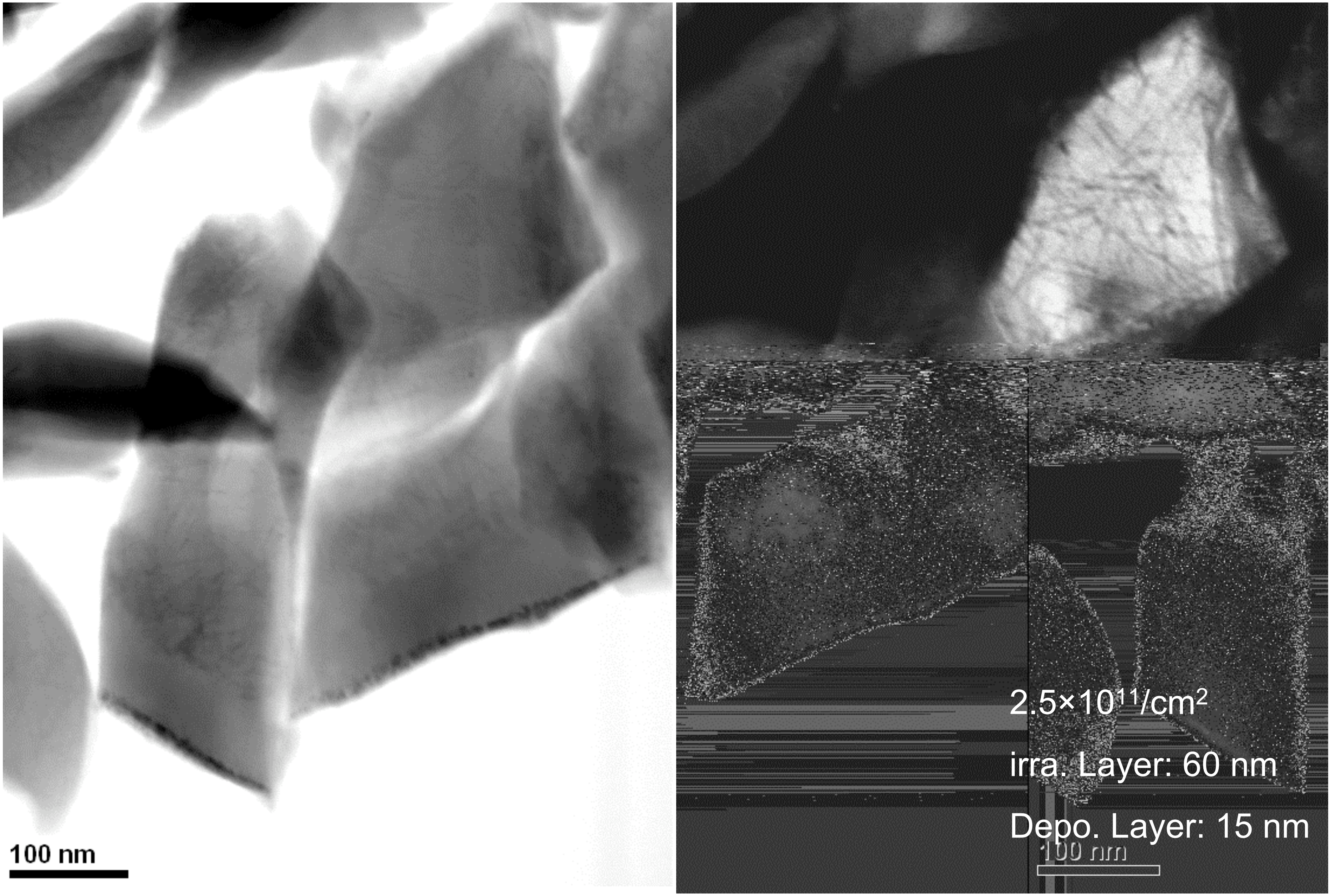


$0.5 \times 10^{11}/cm^2$

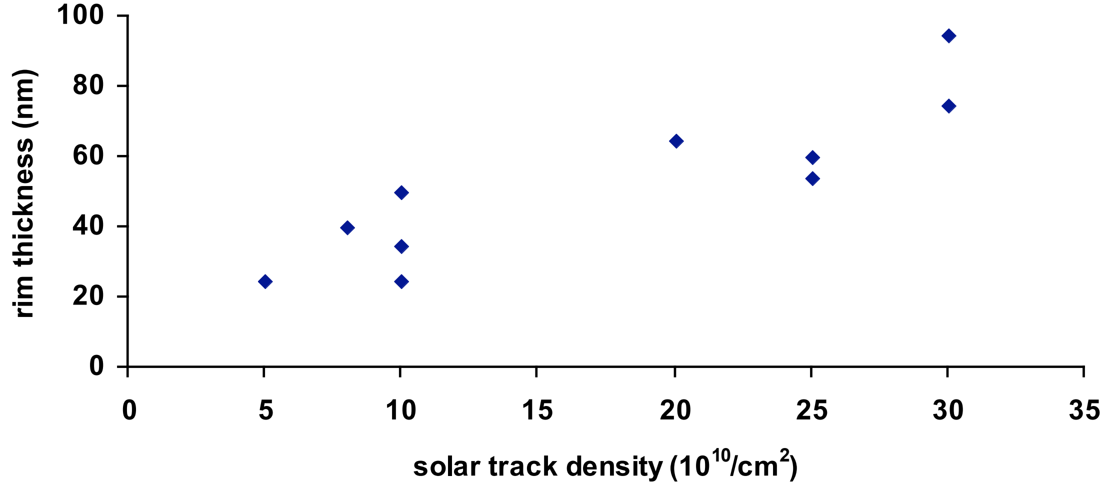
irra. Layer: 25 nm

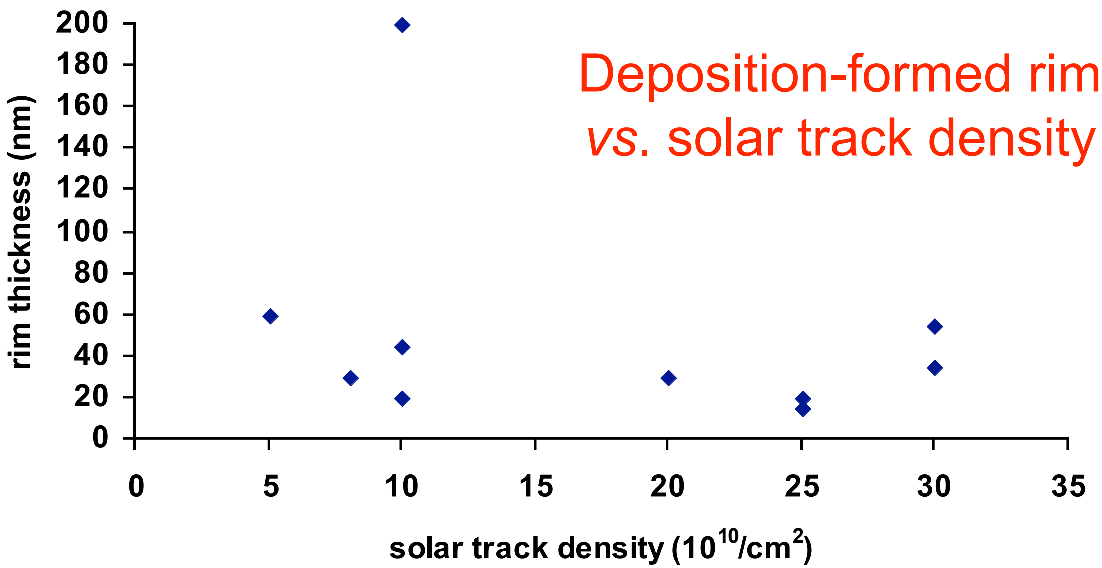
Depo. Layer: 60 nm

Solar track density *vs.* deposition/irradiation



Irradiation-induced rim
vs. solar track density



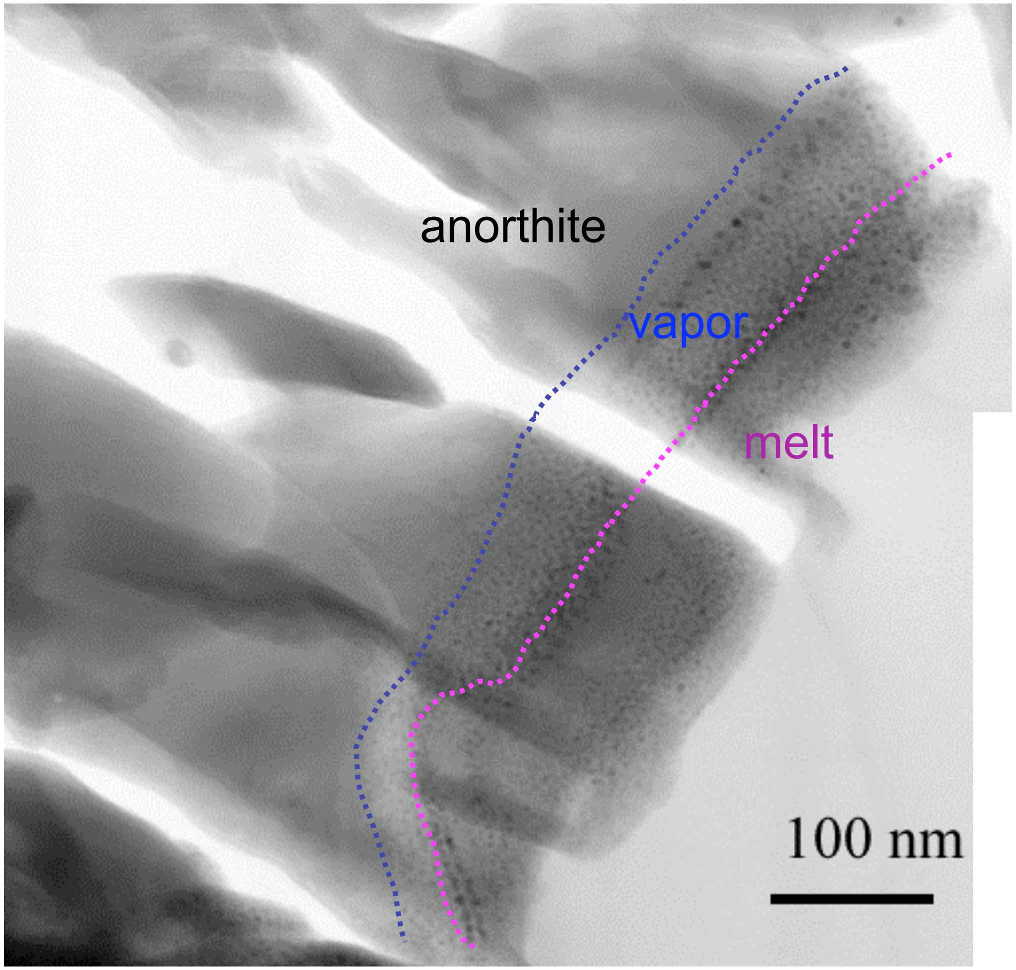


Deposition-formed rim
vs. solar track density

Implication:

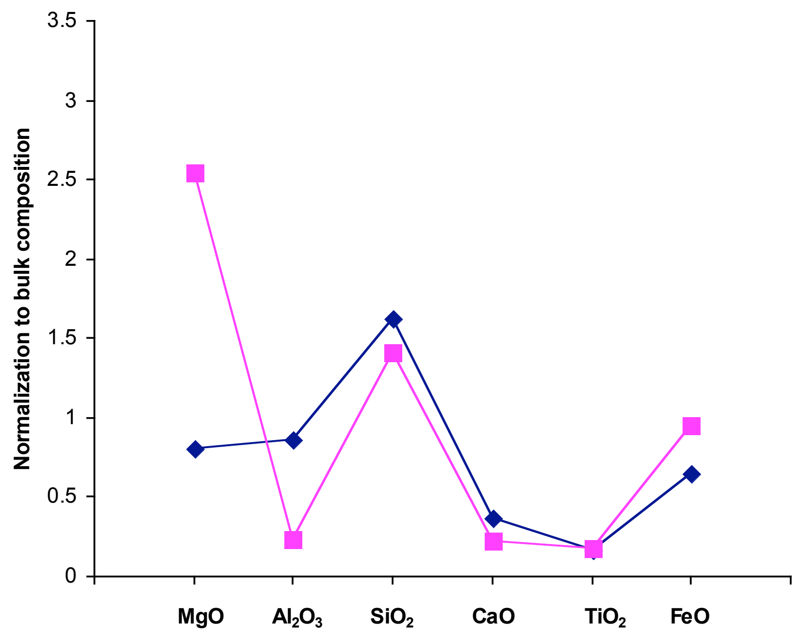
Thickness of the irradiation-induced rim is a function of exposure time. The deposition-formed rim is not time sensitive, which might indicate a single-event deposition or fast accretion, instead of gradually and continuously accumulated.

Evolution of the depositional rim

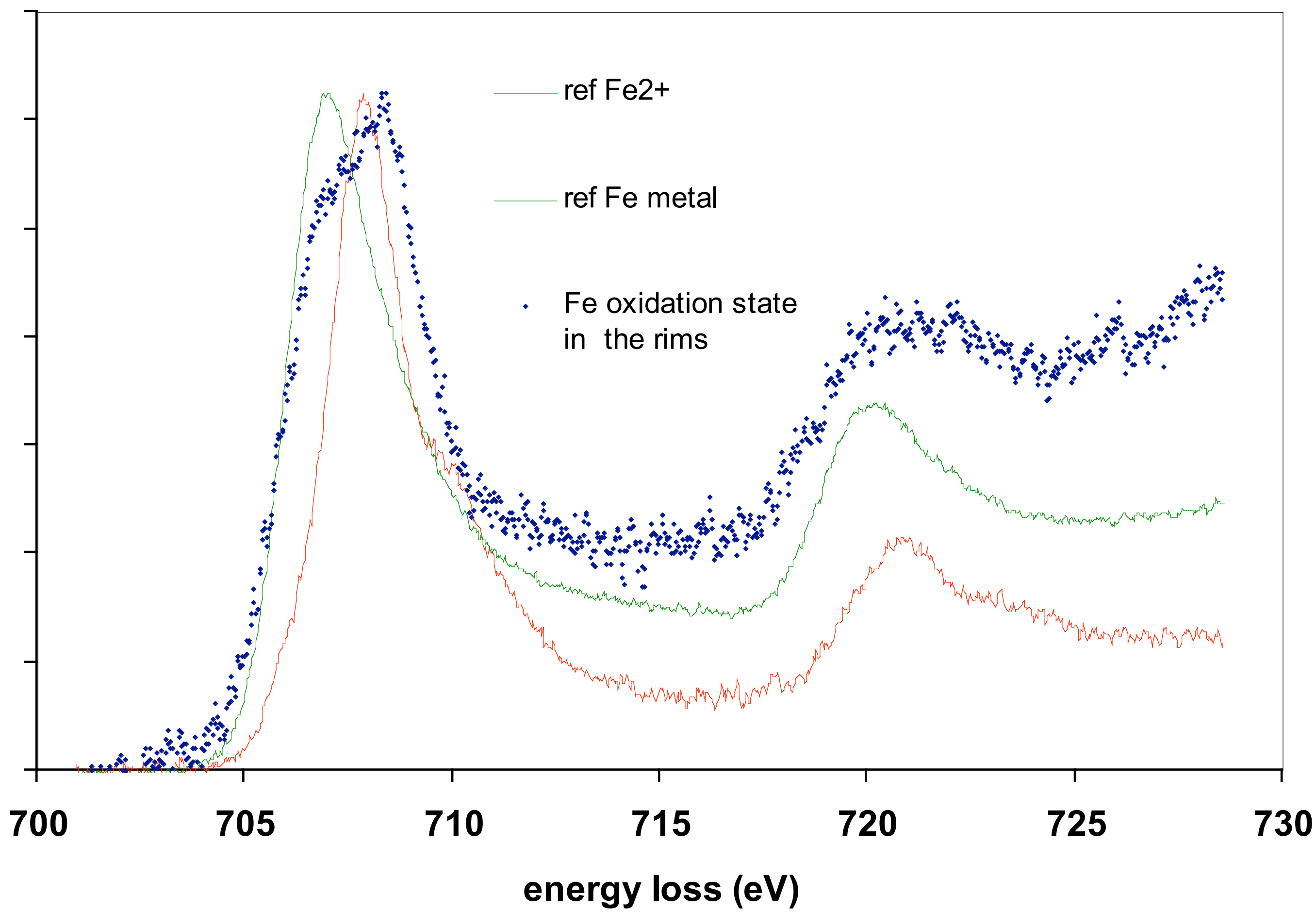


One episode of vapor deposition could be up to 50 nm.

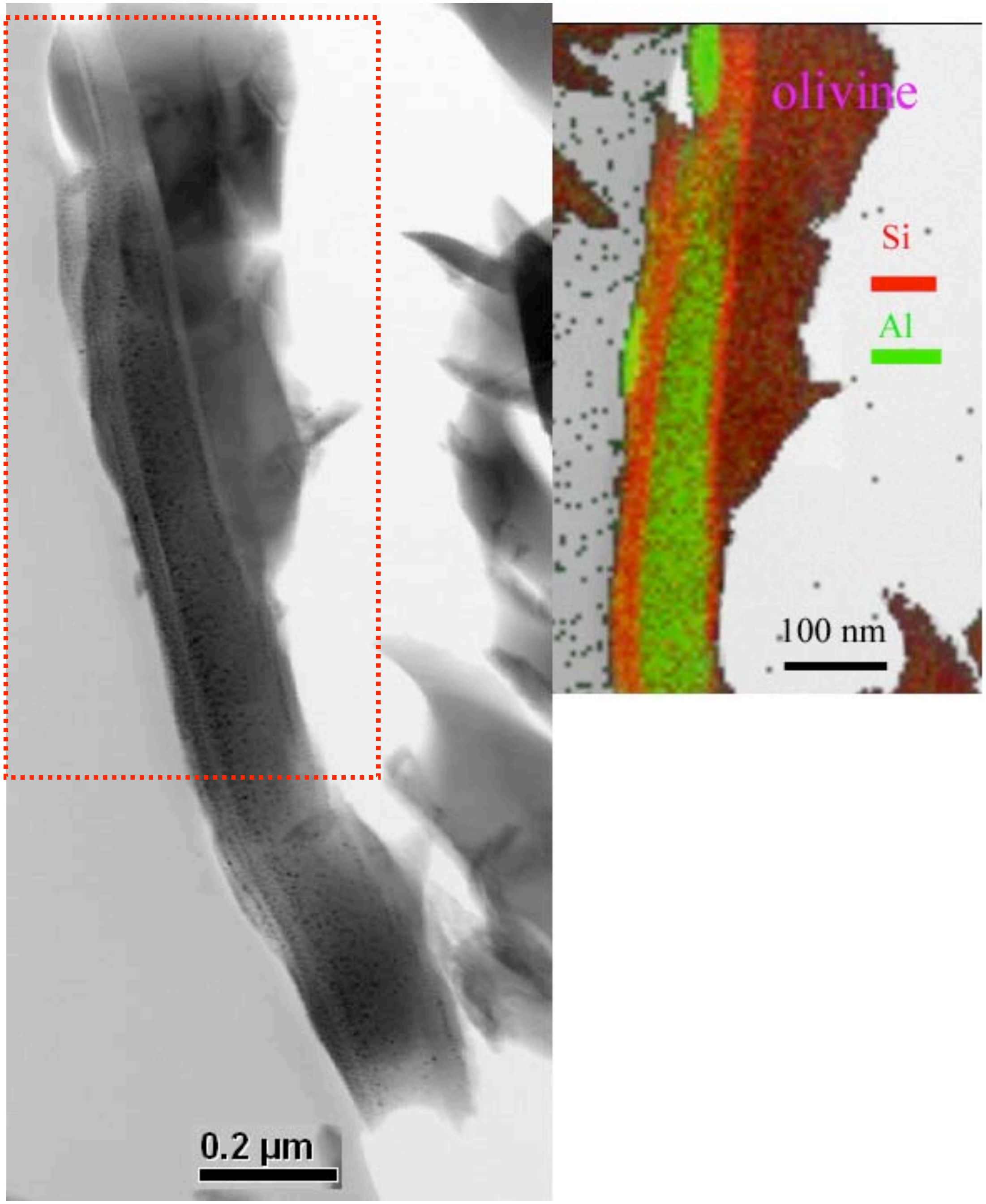
Vapor deposition or melt accretion?



Fe oxidation state in the rim

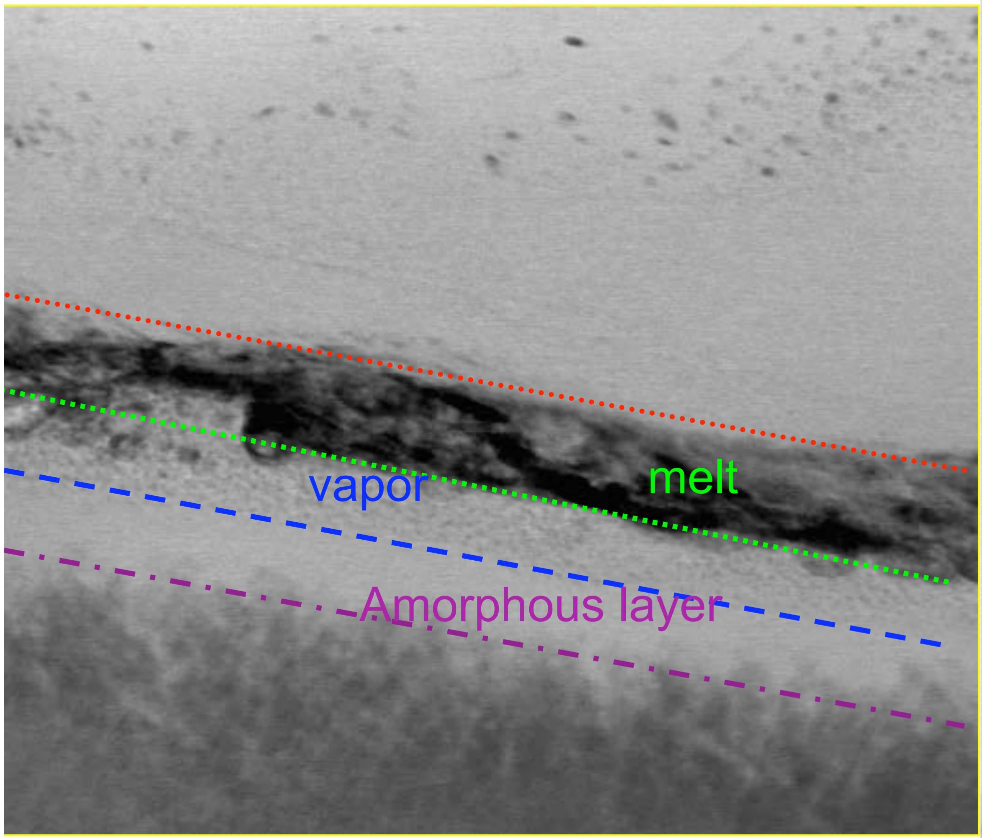


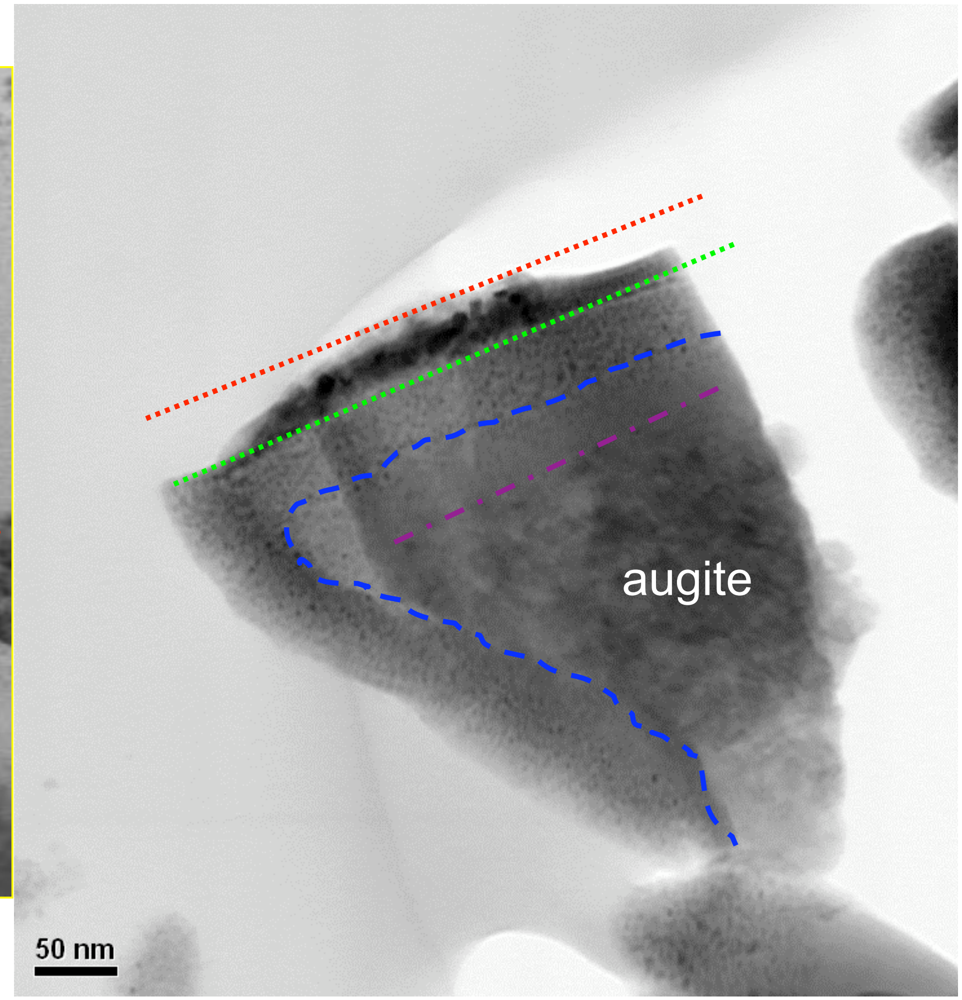
Consistent with the result from the agglutinate glass (Keller et al. 2001)



- Sharp compositional boundaries between different melt layers preserved at nm scale, similar to space weathering effects recorded in lunar rock patina (Noble et al. 2007).

Rock patina *vs.* rims on the soil grains





(Noble et al. 2007)

Conclusions

- Space weathering effects form both radiation-damaged and deposited layers on the surfaces of lunar soil grains.

- The thickness of the irradiation-induced amorphous layers are positively correlated with solar flare particle track density. The deposited layers have a uniform thickness, averaging ~50 nm, independent of track density.

- Melt accretion on grain surfaces is more common than previously thought.

- EDS and EELS analyses suggest a single episode of vapor deposition is <50 nm. The deposited rims >100 nm thickness are most likely accreted melts.

- The deposited rims are the major host of nanophase Fe on grain surfaces.